Direct ascent of asthenospheric melt: Implications for the melt genesis and mantle heterogeneity

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博 士 論 文

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（速やかに上昇したアセノスフェア溶融物：その起源とマントルの不均質性について）

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Petit-spot is alkaline monogenetic volcano distributed at the localities of plate-flexure such as the outer rise prior to plate subduction. Petit-spot volcanism is one of within-plate volcanism which is unrelated to mantle plumes or hotspots as they are randomly distributed without age progressions like a hotspot trail. Petit-spot magmas originate from asthenosphere which move upward through the oceanic lithosphere by tectonic forces associated with plate flexure. Therefore, sampling the petit-spot lavas may be the only way for us to gain the materials directly from the asthenosphere below old and thick oceanic plate. However, the recent research of xenoliths within lavas erupted from these volcanos revealed the evidence of metasomatic interaction between petit-spot magma and wall rocks of the lithosphere during magma ascent (Pilet *et al.*, 2016). Therefore, it is necessary to consider the ascending process and lithospheric interactions when estimating asthenospheric compositions using petit-spot lava samples.

So far, three petit-spot lava fields (Site A, B and C) have been discovered on the northwest Pacific Plate offshore from the central Japan Trench (Hirano *et al*., 2006; Fig. 1.3). Site C is the widest petit-spot lava field of the three, distributed at the top of outer rise offshore from Fukushima and Miyagi prefectures, northeast Japan. More than 80 petit-spot volcanoes have been identified in Site C by shipboard multibeam surveys (Hirano *et al*., 2008), as well as a horst and graben structure in the western part of the region along the Japan Trench. The YK14-05 research cruise explored Site C in 2014, using R/V *Yokosuka* equipped with the submersible *SHINKAI 6500*. This expedition collected petit-spot rock samples from nine volcanoes. This study presents new geochemical data for these petit-spot volcanic rocks and assess the relationship between geochemical variation of samples and tectonic setting (i.e., compression versus extension) as well as the possible existence of magmas that directly ascend from the asthenosphere without stagnation in the mid-depth of lithosphere, and thus discuss the implications for the melt genesis and mantle heterogeneity.

First, the eruption ages of the rock samples from Site C were estimated by using the growth rate of palagonite in glass. The samples from the volcano #1385 showed the youngest eruption age (0.02–0.13 Ma), indicating the eruption site atop of outer rise where the lithosphere bends convexly. This is a rare case because most of petit-spot volcanos erupted at the onset of outer rise formation where the lithosphere bends concavely (Hirano et al., 2006; 2008). In fact, other volcanoes of Site C are considered to have formed at the concavely flexed zone of lithosphere.

In order to compare the characteristics of rocks from two different tectonic settings, the geochemical analysis were performed using X-ray fluorescence spectrometer (major elements of balk rocks), wavelength dispersive electron microprobe (major elements of quenched glasses), inductively coupled plasma–mass spectrometer (trace elements), and thermal ionization mass spectrometer (Sr and Nd isotope).

Results of analysis show that petit-spot rocks which erupted on atop of outer rise are extremely alkaline in comparison to other northwest Pacific petit-spot basalts. Generally, strongly alkaline basalts are often associated with carbonatite. However, Zr/Hf ratios, which represent degrees of carbonatite addition into their source peridotites, of the strongly alkaline basalts are comparable to those of ordinary petit-spot lavas which are not strongly alkaline. Therefore, the alkali enrichment cannot be explained by only the carbonatitic contribution to the source mantle.

Compositional data suggest that ordinary petit-spot magma of northwest Pacific experienced separation of immiscible carbonatite liquid and metasomatic interaction with the surrounding peridotite at the mid-depth of lithosphere. The experimental work of Pilet *et al*. (2008) shows that silica-poor alkaline melts undergo the transition to silica-rich subalkaline melts by metasomatic interaction with lithospheric peridotite. In contrast, strongly alkaline basalts experienced neither separation of immiscible liquid nor metasomatic interaction.

Ordinary petit-spot basalts of northwest Pacific are considered to erupt at the concavely flexed zone of lithosphere such as the region from the onset of outer rise formation. As for the concavely flexed zone, the base of the lithosphere beneath the eruption sites is under extension, whereas the upper part of the lithosphere in under compression. This change in the stress field causes magma stagnation at the mid-lithosphere, leading to separation of immiscible liquid, mineral fractionation and metasomatic interaction. On the other hand, the distributions of the strongly alkaline petit-spot lavas are limited in the extensional tectonic setting such as the top of the outer rise. In the extensional setting, petit-spot magma can ascend directly from the asthenosphere without magma storage in the mid-depth of lithosphere, leading to avoiding various chemical reactions. It is concluded that the lithospheric stress field largely controls the compositional variation of petit-spot magmas.

Discover of direct-ascended petit-spot basalts could contribute to provide more detailed geochemical information of oceanic upper mantle because the geochemical modification of these magmas is predicted to be minimal. This study provides the isotopic composition data of direct-ascended basalts, which reflect the characteristic of the mantle source and the ascending process. Ordinary petit-spot basalts of northwest Pacific represent EM-1-like characteristics. In contrast, Sr-Nd isotopic compositions of the strongly alkaline basalts clearly show lower $^{87}Sr/^{86}Sr$ ratio and higher $^{143}Nd/^{144}Nd$ ratio than other northwest Pacific petit-spot basalts, suggesting contribution of HIMU mantle components, which represent ancient carbonatite-metasomatized subcontinental lithospheric mantle. This suggests that there could be not only the EM-1 components but the HIMU components embedded in the upper mantle beneath the northwest Pacific. It is further suggested that ordinary petit-spot basalts erupted on the concavely flexed zone were isotopically affected by EM-1 components during magma stagnation at the mid-depth of lithosphere because isotopic compositions of direct-ascended basalts are closer to HIMU end member than others.

Petit-spot volcanism is considered to be ubiquitous phenomenon on all flexed parts of the oceanic lithosphere. Direct-ascended petit-spot basalt is rare, but it should occur on the concavely flexed regions of the oceanic lithosphere of the world. It is expected that further study on the direct-ascended petit-spot basalts will shed light on the petrological and geochemical nature of the upper mantle hidden in the deep Earth.